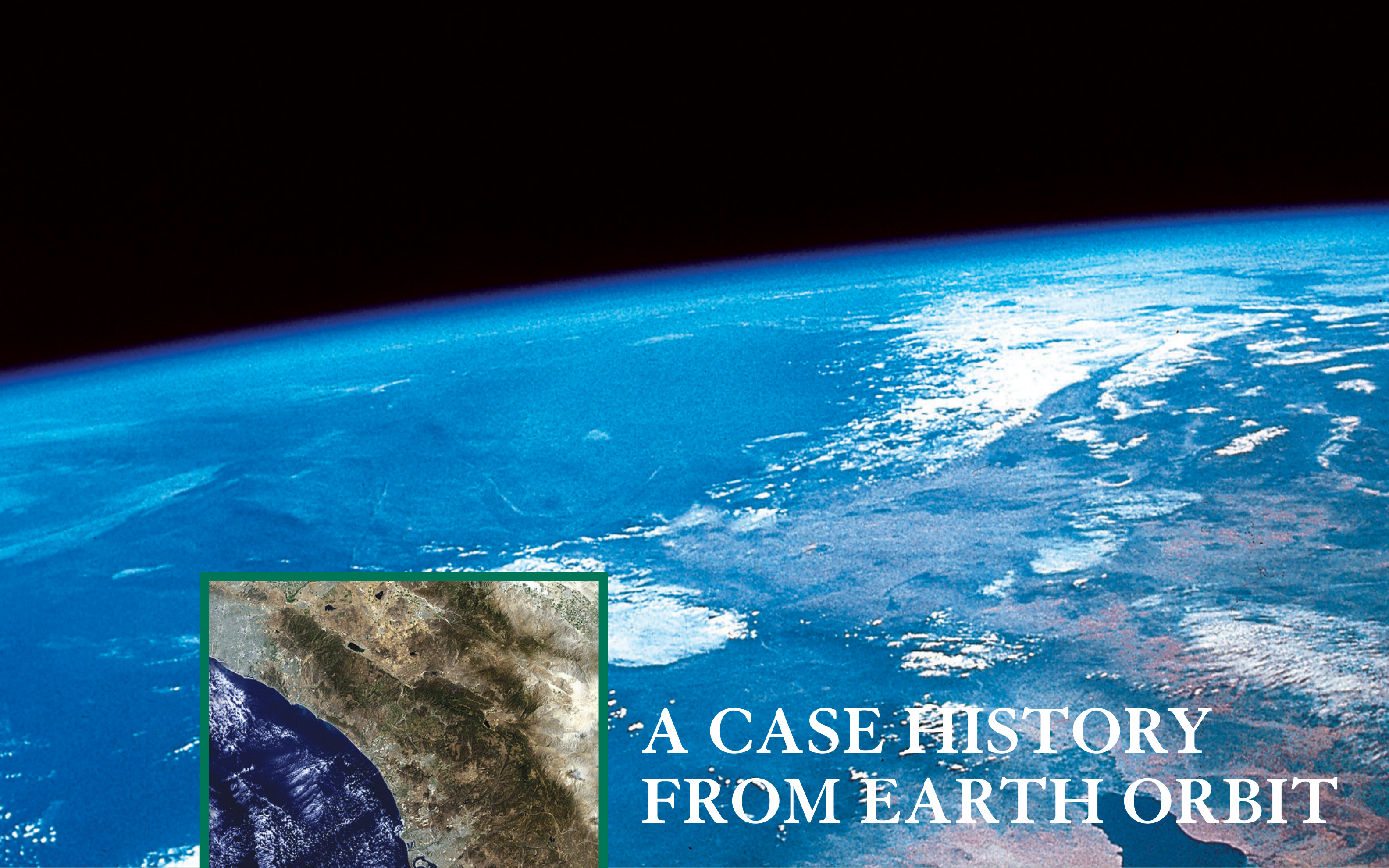

A CASE HISTORY FROM EARTH ORBIT

EXPLOR

By Paul D. Lowman, Jr.

Having judged dozens of science fairs over the years, I am repeatedly disturbed by the ground rules under which students must prepare their entries. Students are almost invariably required to follow the "scientific method," which involves formulating a hypothesis, a test of the hypothesis, and then a project in which the test is carried out.

As a research scientist for over 40 years, I consider this approach to science fairs fundamentally unsound. Not only is it too restrictive, it also avoids the most important (and difficult) part of scientific research: recognizing a scientific problem in the first place. Physics, for example, was transformed by Einstein's recognition of a problem that, by his own account, stimulated his theory of special relativity. He pointed out that when an electric current is induced in a conductor by a magnetic field, it makes no difference whether the field or the conductor is actually (so to speak) moving. There is, in other words, no such thing as absolute motion.

About the author

Paul D. Lowman, Jr. is a geologist at NASA's Goddard Space Flight Center in Greenbelt, Md. The first geologist hired by NASA in 1959, he has been involved in a wide range of programs, both those focused on the Earth from space and those aimed at the Moon and planets. This dual career has given him an unusually broad view of geologic problems.

Dr. Lowman attended Rutgers University, earning a B.S. in geology in 1953. After two years of service in the U.S. Army, he earned a Ph.D. in geology from the University of Colorado. His research at Goddard Space Flight Center, now spanning 42 years, has included geology of the Moon, remote sensing, comparative planetology, and global tectonics. He was principal investigator for several terrain photography experiments on Mercury, Gemini, and Apollo Earth orbital missions. He took part in analysis of lunar samples returned by the Apollo missions and in lunar remote sensing experiments on *Apollos 15* and *16.* He was co-investigator for infrared spectroscopy on the Mariner 9 Mars mission.

Dr. Lowman worked for several years in cooperation with the Canada Centre for Remote Sensing, using orbital radar to study crustal structure in North America. His work for the last several years has concentrated on compiling a digital tectonic map of Earth, showing tectonic and volcanic activity during the past one million years. He is the author of Exploring Space, Exploring Earth: New Understanding of the Earth from Space Research, published July 2002 by Cambridge University Press.

ATION SCIENCE

Most competent scientists can solve problems after they are recognized and a hypothesis is properly formulated, but the ability to find problems in the first place is rare. The scientific method under which almost all students are required to operate should be termed the experimental method, which involves controlled variables that are changed one at a time. However, there is another type of science that can be called observational, or exploration, science. Observational science projects take the world as it is (rather than trying to experimentally control selected aspects) and involve genuine exploration, even if limited to a back yard. As it happens, almost all the space research I have carried out since 1959 has been observational in nature.

The most obvious example of observational science is astronomy. We have no way to control the many variables involved in, for example, star formation. Back on Earth, oceanography, meteorology, and much of geology are largely observational, as are exploration and mapping in general. The observations in these fields can result in star catalogues, geologic maps, or collections of fossils. Such observational science is generally the foundation for subsequent scientific research, promoting recognition of previously unknown problems or questions. After a problem has been recognized, efforts to solve it involve construction of hypotheses, which are then tested by the experimental method or further observations.

A case history

To illustrate the interplay of observation, problem recognition, and hypothesis testing, I provide here a condensed

FIGURE 1

Geologic structure of the southwest United States.

Photomosaic from the *Landsat 1* satellite. S.J.F. stands for San Jacinto Fault.

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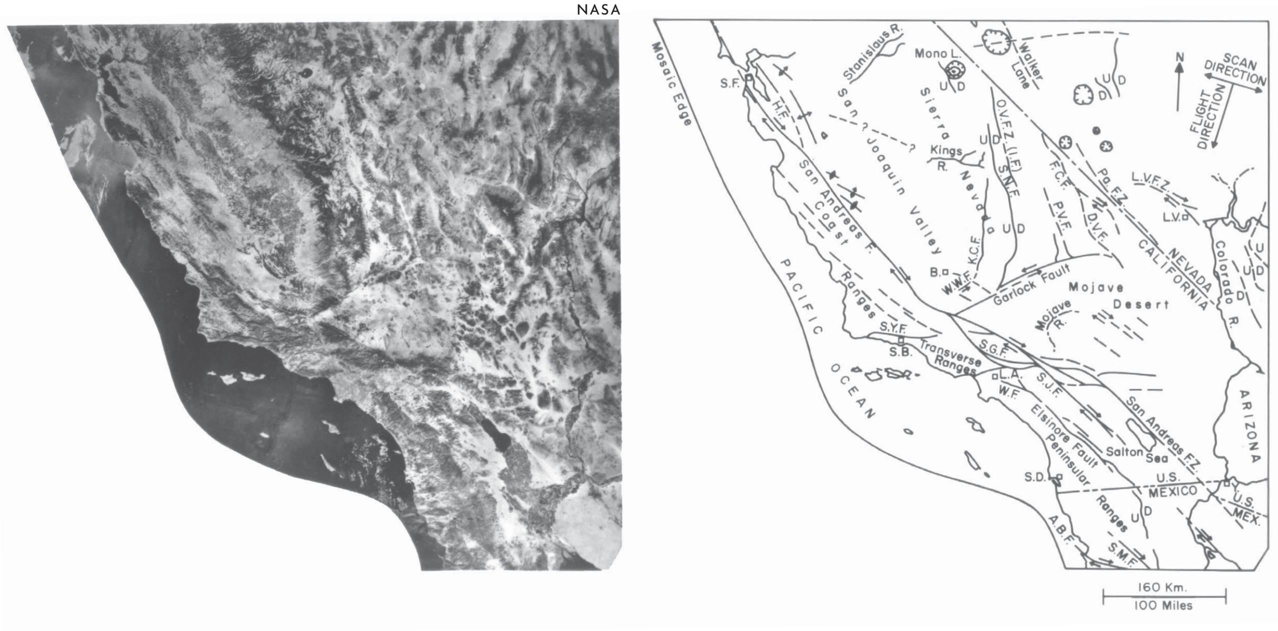


FIGURE 2

The Salton Sea.

Image taken in 1965 from *Gemini 5* at 240 km altitude, looking northeast across the sea. Notice the prominent linear feature extending from the lower left corner toward the upper right, crossing the Elsinore Fault.

NASA

example from my own research—a study of the Elsinore Fault in southern California based on 70 mm terrain photographs taken by astronauts on the Gemini 5 and Apollo 9 missions in 1965 and 1969, respectively.

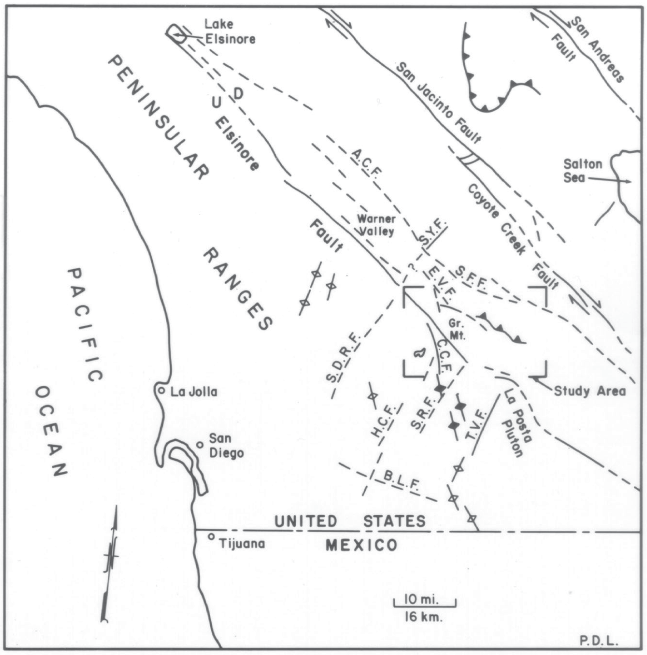
The Elsinore Fault, roughly 200 km long, is a seismically active fracture parallel to the segment of the San Andreas Fault east of San Diego (Figure 1). It forms the east face of the southern California batholith, the southern equivalent of the Sierra Nevada batholith—enormous composite igneous intrusions of granitic rock. Topographically, the fault bounds the crest of the Peninsular Ranges, though this crest is by no means the highest point.

The Elsinore Fault is considered part of the San Andreas system, sharing the regional interplate shearing motion by slipping in a right-lateral sense (opposite side of the fault moving to the right, as seen from either side). The current interplate motion between Pacific and North American plates in this region, as measured by space geodesy, is roughly 4–5 cm per year, distributed across a broad zone of faulting. Authoritative estimates in the 1960s of the total displacement on the Elsinore Fault were around 30 km of horizontal movement (“strike slip” in geologic terms). Some geologists, to allow for the possibility that less prominent faults just to the east may share in this movement, have used the term “Elsinore Fault zone.”

FIGURE 3

Peninsular Ranges, southern California.

Image taken in 1969 from *Apollo 9* at 250 km altitude.



Legend

Major fault - - - - -

A.C.F–Aqua Caliente
B.L.F.–Barrett Lake
C.C.F.–Chariot Canyon
E.V.F.–Earthquake Valley
H.C.F.–Horsethief Canyon
S.F.F.–San Felipe
S.D.R.F–San Diego River
S.R.F.–Sawtooth Range
T.V.F.–Thing Valley

Thrust Fault; barbs on upper block

Generalized foliation in steeply dipping metamorphic or igneous rocks

In 1965, astronauts Pete Conrad and Gordon Cooper on the Gemini 5 Earth orbital mission took a striking 70 mm color photograph of the Salton Sea (Figure 2), probably to show the conspicuous gyre (a large circular current) resulting from suspended sediment stirred up by wind from the north. As principal investigator for terrain photography (Lowman 1969), I was asked by the Educational Programs Office at Goddard Space Flight Center to draw a sketch map of the photo showing the San Andreas Fault. The fault's location is well known and was easy to plot. However, several other prominent faults parallel to it were also visible, notably the San Jacinto and Elsinore Faults, so I plotted them as well. I noticed an anomaly: a prominent linear feature (lower left corner) extending northeast across the Elsinore Fault without any apparent lateral offset. Because the Elsinore was considered a strike-slip fault, similar to the San Andreas Fault, I wondered how these relations could be reconciled with the prevailing interpretation of the Elsinore Fault. This was the crucial event—recognition of a problem.

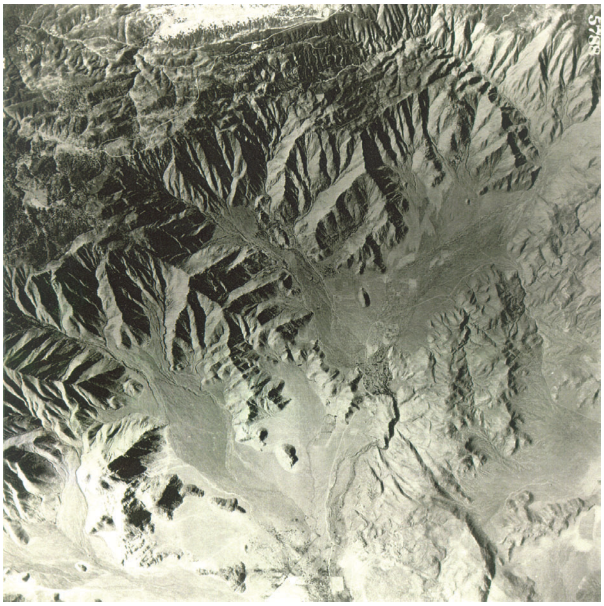
The space program was moving at a frenetic pace in the mid-1960s, and I was unable to investigate the Elsinore Fault problem at the time. However, in 1969 the *Apollo 9* crew, Jim McDivitt, Dave Scott, and Rusty Schweikart, carried out systematic multispectral 70 mm photography intended to demonstrate the feasibility of imaging similar in principle to that of the planned *Landsat* satellite system. The superb vertical photographs included one of San Diego and the adjacent Peninsular Ranges, including the Elsinore Fault (Figure 3). The crosscutting feature I noticed on the *Gemini 5* picture from before was now shown in true geometry and with high resolution. It was a deep valley, occupied by the San Diego River, that apparently continued as San Ysidro Creek northeast of the Elsinore Fault. However, the Apollo 9 photo showed several other northeast-trending features, at least one of which also crossed the Elsinore Fault without lateral displacement. The age relationships, incidentally, are clear; the northeast-trending features are clearly old, judging from their topography, whereas the Elsinore Fault is seismically active and is known to be slipping now, although the rates and directions are still poorly known.

Up-close observation

In 1970 I was invited to teach two courses at the University of California in Santa Barbara during the three-month winter quarter. While there, I had the opportunity on weekends to do field work in San Diego County. My first objective was simply to find out what the northeast-trending features were. I found that topographically they were primarily valleys, following fractures of some sort—faults or joints. However, one of the Elsinore Fault–crossing features was a straight valley in the

FIGURE 4

Aerial photograph of Sawtooth Range.

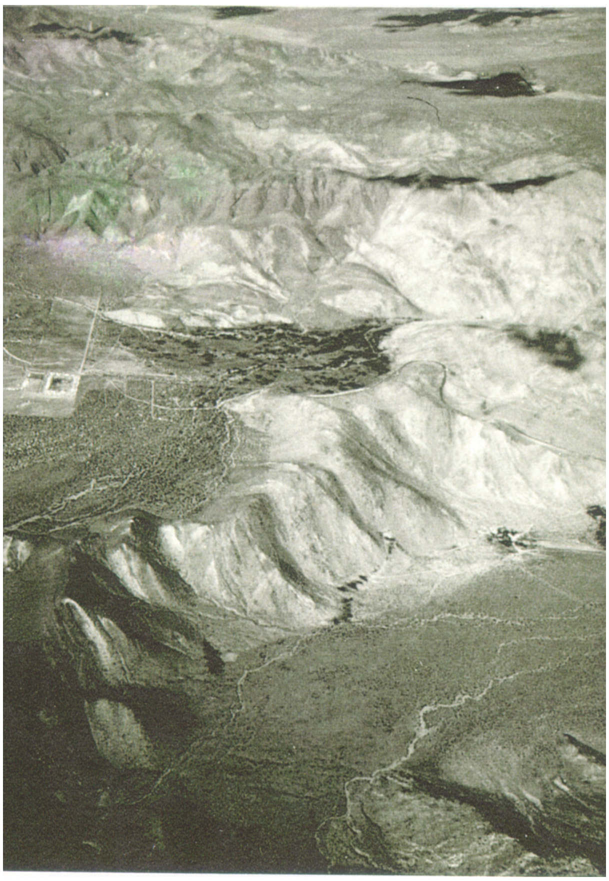


U.S. GEOLOGICAL SURVEY

FIGURE 5

Sawtooth Range at Campbell Grade.

Photo taken by handheld 35 mm camera looking northeast. Elsinore Fault exposed in hairpin turn on top of ridge, upper right, on San Diego County Road S 2.



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mountains west of the Elsinore Fault with a ridge east of it. Topographic maps showed the ridge to be the Sawtooth Range, a somewhat pretentious name for a small spur of the mountain front. The Sawtooth Range, unlike the other features, was largely on public land and easily reached by good roads. I therefore decided to study its structure where it was cut by the Elsinore Fault.

To examine this critical area more closely, I obtained high-altitude air photos from the U.S. Geological Survey (Figure 4), and, some years later, satellite pictures from *Landsat*. In addition, with two California colleagues, Jack Estes and Bill Finch, I hired an aircraft and pilot to take us on a two-hour photoreconnaissance flight over the Peninsular Ranges. Among the 35 mm pictures I took was Figure 5, an oblique view of the Sawtooth Range at its intersection with the Elsinore Fault.

Revisiting the problem

The space program's pace was increasing, and I became involved in *Landsat,* and the Mariner 9, Apollos 15 and 16, and the Voyager missions. The Elsinore Fault anomaly was therefore put on the shelf for several years, except for an occasional day stolen from California trips for other purposes. However, I continued to study the problem, publishing a preliminary report in 1976 (Lowman) after *Landsat* pictures became available. In 1979 I spent several days mapping the bedrock structure of the Sawtooth Range and the areas to the east, where

FIGURE 6

Outcrop view of fault plane of Elsinore Fault at Campbell Grade.

Image shows slickensides indicating dip slip for last movement.

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related faults possibly exist. My findings were that the structure exposed as foliation in Cretaceous age metamorphic rocks and flow structure in igneous rocks was continuous across the Elsinore Fault and other faults to the east, with no lateral offset at all.

The culminating observation was in a road cut (locally known as Campbell Grade) on the Sawtooth Range where an actual plane of the Elsinore Fault was exposed (Figure 6). This smooth surface was strongly grooved (slickensides, in the geologic term), with the grooves oriented straight down the fault plane. Slickensides obviously give the direction of the slip along the fault, or at least the most recent slip. Those in the road cut clearly indicated vertical movement, directly contrary to the prevailing interpretation of the Elsinore as a fault with major horizontal movement. Again, this fault is seismically active, and if slipping horizontally at even half a centimeter per year (a 1996 estimate), the Sawtooth Range would have been offset at Campbell Grade by 100 m in only 20 000 years.

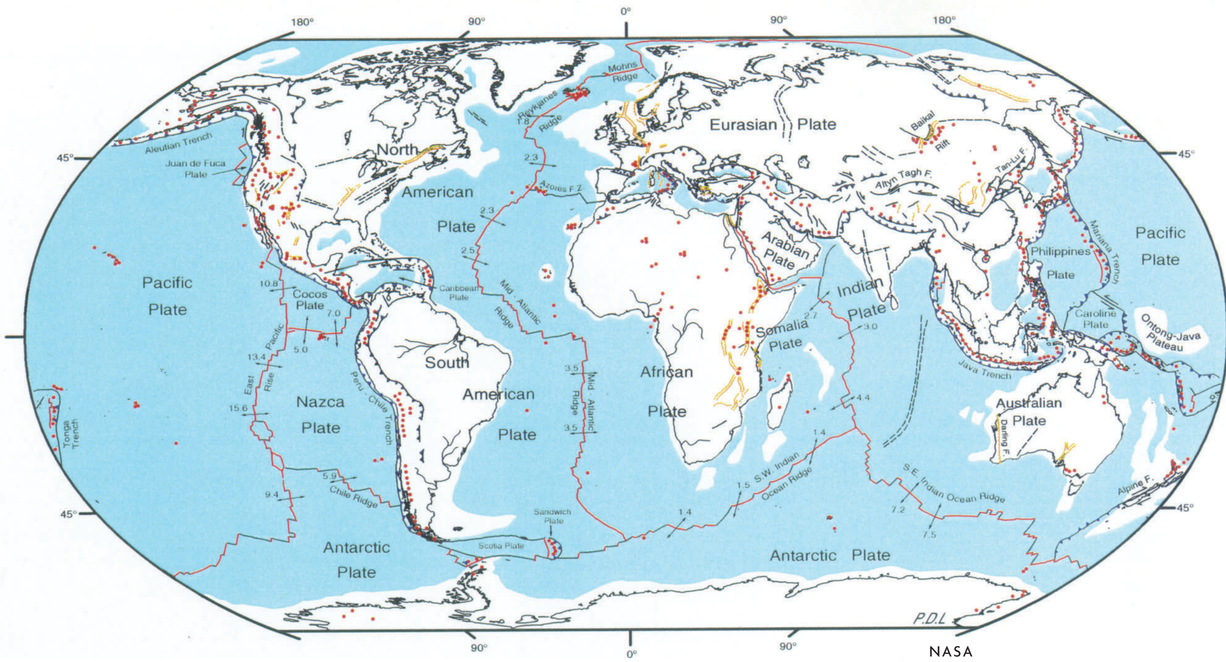
Two California geologists, Vicky Todd and Wendy Hoggatt, doing geologic mapping for other purposes, confirmed my findings independently. Paul Merifield and Don Lamar, using *Skylab* and *Landsat* satellite pictures, arrived at the same general conclusion for the Elsinore Fault. I therefore wrote a paper for the *Journal of Geology* (Lowman 1980) in which I showed that the Elsinore Fault was not a strike-slip one, but characterized by vertical movement. After peer review, the paper was published in 1980.

To summarize this case history, observational science permitted recognition of a scientific problem, namely the apparent evidence against the prevailing interpretation of the Elsinore Fault as having many kilometers of lateral offset. This interpretation was the hypothesis to be tested. It was tested by doing several years of intermittent field mapping and further observations. The final critical observation was the discovery of slickensides oriented up and down, not horizontally. To the extent that the Elsinore Fault is a single feature, and that the Campbell Grade exposure is representative, the hypothesis was disproven. I had also mapped two parallel subsidiary faults to the east, finding no evidence for horizontal motion on them either (Lowman 1980).

The experimental method played no role at all in this hypothesis testing; the project was purely observational. Experimental and observational science are not mutually exclusive. The overall approach in the Elsinore Fault study, once the problem had been recognized, was similar to that of the experimental method. The crucial part of this study was discovery of the problem itself. The subsequent field mapping was by professional standards fairly straightforward and could have been done by a third-year geology student with strong legs and cactus-proof boots. But it led to an interpretation directly contradicting the views of the most eminent California geologists of the day.

FIGURE 7

Global tectonic activity map of Earth.



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Handheld astronaut photography similar to that illustrated in this article was resumed when the shuttle started flying in 1981, under the Space Shuttle Earth Observation Program administered by Johnson Space Center. Tens of thousands of color pictures have been taken over the decades; some of the best are shown in "Orbit: NASA Astronauts Photograph the Earth," published by the National Geographic Society (Apt et al. 1996). These pictures, and in fact all astronaut photographs taken since 1962, can be viewed on the Internet at *http://eol.jsc.nasa.gov/sseop*.

I recommend that science teachers limit their objectives when asking students to make observations, such as hand-drawn and documented maps of interesting land areas or features. The simplicity of the Elsinore Fault study described here may be deceptive; it was done by an experienced Ph.D. and took years of work. But there are many parts of Earth, especially in desert areas such as North Africa and Australia, where unexpected anomalies may be found, and problems to be solved at least outlined.

My California fieldwork was intensely interesting, physically and intellectually challenging, and carried out in magnificent country. My memories are a montage of desert flowers in springtime; 100° temperatures in the Imperial Valley; outcrop graffiti from the 19th century, when Campbell Grade was a stagecoach route; finding a jettisoned canopy from a Navy A-4 jet fighter (presumably the pilot survived); scrambling down a cactus-covered slope in near darkness; rationing my quart of water through a day of desert heat; and coyotes sounding the alarm that there was an intruder on Vallecito Creek. So if any readers use my example in class, please tell the students that it was great fun.

Encouraging exploration

The intent of this case history is to encourage science fair organizers to permit students to submit observational science projects, not just experimental ones. Such projects, especially carried out by younger students, may not get as far as the formulation of a hypothesis or even the identification of a problem. But they would be the same kind of science carried out by Charles Darwin in his five-year voyage on the *Beagle:* the collection of knowledge about the natural world or some aspect of it.

Science projects of this sort could be as simple as a map of weed species in a backyard, a labeled and location-keyed collection of local rocks, a meteor count, a photographic atlas of cloud types, a soil profile from a garden, or a species count of birds at a backyard feeder. Students might do a UFO watch, in which they record *everything* they see in the sky—constellations, planets, airplanes, bats, satellites, aurorae, and meteors—during a one-hour period shortly after sunset.

Projects could be more ambitious, such as an analysis, however elementary, of a recent image of Earth from space similar to my Elsinore Fault project. Such pictures are now plentiful and easily obtained through the Internet. Several major earth-observing satellites are operated by NASA, including *Landsat 7, EOS Terra,* and *EOS Aqua,* in addition to others that produce largely nonvisual data. These satellites generate and transmit enormous amounts of information to Earth every day, some of which should be usable by students for observational science projects.

A good starting point for this is the NASA Earth Observatory "Image of the Day," which can be downloaded from the Internet at *http://earthobservatory.nasa.gov*. One of the sites listed under the Earth Observatory is a digital tectonic activity map (Lowman et al. 1999; Lowman 2002), illustrated in Figure 7, page 29. This map and several coregistered ones, such as seismic activity, can be accessed at *http://denali.gsfc.nasa.gov/dtam*. They may be useful in picking areas for study and in interpreting images acquired.

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